angle; dz for each half degree of latitude and azimuth is given in the table. All that one has to do to obtain the "reduction" is to take the approximate azimuth from any azimuth tables—and this has to be done for another part of the problem—then take out the rate of change, dz, from the Goodwin table and multiply this by the number of minutes in the hour angle.

RETURN OF BROOKS'S COMET.—A telegram from Kiel announces that Brooks's comet was observed by Prof. Aitken at the Lick Observatory on August 18, and that the position of the comet at 12h. 17·4m. (Lick M.T.) on that date was R.A. = 21h. 2m. 51·3s., Dec. = $-27° 4' 19''$. This position agrees closely with that given by an ephemeris computed by Herr P. Neugebauer, and published in No. 3868 of the *Astronomische Nachrichten*. The following is an extract from this ephemeris:—

Ephemeris 12*h*. (*M.T. Berlin.*)

1903	True α h. m. s.	True δ ° ′ ″	log *r*	log Δ
Aug. 27	20 56 24·95	−27 0 30·4	0·3284	0·07060
,, 29	20 55 12·95	−26 57 6·4		
,, 31	20 54 6·78	−26 52 54·0	0·3259	0·07321
Sept. 2	20 53 6·98	−26 47 53·8		
,, 4	20 52 13·90	−26 42 6·8	0·3234	0·07693
,, 6	20 51 27·98	−26 35 33·6		
,, 8	20 50 49·45	−26 28 15·2	0·3210	0·08165
,, 10	20 50 18·61	−26 20 12·8		
,, 12	20 49 55·67	−26 11 27·7	0·3187	0·08727
,, 14	20 49 40·87	−26 2 1·0		
,, 16	20 49 34·32	−25 51 53·8	0·3164	0·09369
,, 18	20 49 36·19	−25 41 7·0		
,, 20	20 49 46·55	−25 29 41·9	0·3142	0·10081

According to Aitken's determination of the comet's position, as given above, this ephemeris needs a correction of +22·58s. in R.A. and $+1' 41''·2$ in Dec.

Although not a bright object, this comet is of historical interest, because when it was first discovered by Brooks, in 1889, it was held to be a good illustration of the "capture theory" of comets, and was looked upon as identical with Lexell's lost comet of 1770, which had been "captured" by Jupiter. This belief was, however, discountenanced by the subsequent researches of Dr. Poor, of Baltimore. In 1889 Barnard observed the comet as double, and found that the two parts were slowly separating.

This comet has a period of 7·096 years, and was duly observed in 1896, when it performed its perihelion passage on November 4. For the present return the comet takes the designation 1903 *d*.

EPHEMERIS FOR COMET 1903 *c*.—An ephemeris for comet 1903 *c* is given in No. 3890 of the *Astronomische Nachrichten* by Herren M. Knapp and W. Dziewulski.

The comet is now too near the sun to be observed but it will be observable by astronomers residing in the southern hemisphere after the middle of September.

α CORONÆ A SPECTROSCOPIC BINARY.—Using the 80cm. refractor and the No. 1 spectrograph of the Potsdam Observatory, Prof. Hartmann has determined that the radial velocity of α Coronæ Borealis varies from −20km. (May 28, 1902) to +38km. (June 3, 1902). The observations extended over the period May, 1902–July, 1903, and the respective velocities were determined from measurements of the lines Hβ, Hγ, Hδ, λ 4481 (Mg) and λ 3934 (Ca). The period of the binary is given as about 17 days (*Astronomische Nachrichten*, No. 3890).

THE ALLEGHENY OBSERVATORY.—In his report for 1902 the director, Prof. F. L. O. Wadsworth, laments the fact that the new observatory buildings and their equipments are not yet completed, and especially urges the necessity for mounting and housing the new 30-inch refractor, the discs for which have already been received from Mantois, of Paris; for this purpose a fund of sixty-five thousand dollars is required, none of which is yet subscribed or provided for.

An excellent electrical equipment for lighting and heating, and for all kinds of experimental work, has been donated by Mr. Westinghouse.

An efficient time service was maintained throughout the year 1902 in spite of instrumental difficulties. General observational work has had to be suspended pending the removal to the new observatory. A large number of mathematical researches have already been carried out, and others are suggested for future attention, by the director.

The latter part of the report is devoted to an outline of the work it is proposed to do when the new observatory is in full swing; this work includes exhaustive daily observations of all the solar phenomena and seismographic, gravitational, and magnetic observations.

THE RELATIONS BETWEEN SCIENTIFIC RESEARCH AND CHEMICAL INDUSTRY.[1]

THE particular branch of science with which I have been asked to deal at this meeting of university extension students—viz. chemistry—is perhaps better calculated to illustrate the intimate connection between scientific research and *productive* industry than any other subject. I emphasise the term *productive* industry because it is desirable to distinguish between productiveness and trade, *i.e.* buying and selling. With the latter I have nothing to do beyond pointing out the very obvious principle that, without something to buy or sell, there would be no commerce, and consequently productive industry must be put into the first rank. Now chemical products of various kinds are absolutely indispensable to all civilised nations. You may remember that many years ago Lord Beaconsfield said that the state of trade could be gauged by the price of chemicals. A writer in the *North American Review* in 1899 published an article in which he laid it down that the nation which possessed the best chemists was bound to come to the forefront in the struggle for industrial supremacy. Of course, "there is nothing like leather," and I am bound to agree with him. Had he been an engineer or an electrician he might perhaps have said the same for mechanical or electrical engineering. At any rate, it is perfectly safe to generalise his statement, and to declare that the nation which possesses the most highly trained technologists is bound to take the lead.

In so many ways does chemistry come into contact with nearly every branch of industry that it is difficult to know where to draw the line in giving actual illustrations of the industrial results achieved through chemical research. It is not possible logically, for example, to distinguish between the results obtained through research directed towards the solution of a particular industrial problem and the results obtained as by-products in the course of purely scientific investigation. Industry has been advanced, and always will be advanced, by both methods. Bearing in mind also that chemistry, in its widest sense, is essentially the science of matter—at any rate until the physicist has electrified matter into his own domain—it is evident that we are concerned not only with the production of useful materials for direct consumption, but also with the production of materials required in other industries. Thus chemistry affects engineers through the metals, cements, and other materials used for constructive purposes, and through the fuels used as sources of energy; it affects the agriculturist on account of the relationship between the growing plant and the composition of the soil, as well as through the relationship between the composition of crops and their value as food-stuffs; it supplies materials for the pharmacist, for the manufacture of pottery, glass and soap, for the paper maker, for the dyer and colour-printer, for the bleacher, tanner, brewer and spirit distiller; it furnishes the explosives used in modern warfare, and it supplies photography with all the materials necessary for the practise of that art. Among later developments it may be claimed that the modern science of bacteriology is the outcome of chemical research, and the manufacture of anti-toxins—the industrial result of this science—has until quite recently been in the hands of the chemical manufacturers. I may remind you also that many important products such as sodium, aluminium, phosphorus, calcium carbide, caustic soda, and chlorine are manufactured by electrical processes, so that the demand for these products has given an impetus to the development of applied electricity.

[1] A Lecture delivered at the University Extension Meeting at Oxford on August 3, by Prof. Raphael Meldola F.R.S.

It is obviously impossible in view of the enormous range of industry in which chemistry is directly or indirectly concerned to do more on the present occasion than take a cursory glance at a few of the more striking cases illustrative of the connection between research and industry. As an example of the creation of an industry through research directed towards a special end, attention may be directed to the manufacture of optical and other glass at Jena. The history of this branch of manufacture, and the results achieved, have been fully described by Dr. Hovestadt in a work published three years ago, and of which a translation, by Prof. and Miss Everett, has been recently published in this country. I must refer you to this work for full particulars. The physical requirements to be complied with in order to produce the most perfect glass for the construction of lenses for optical instruments had long been known, and many attempts had been made to realise these conditions in practice. A visit to the international exhibition of scientific apparatus in London in 1876 led Prof. Abbe to direct attention once again to the fact that the future perfection of the microscope lay with the glass-maker, and in 1881 he, in conjunction with Schott, commenced a set of experiments having for their object the production of a series of glasses of known composition, the optical properties of which were concurrently determined by measurements made by Prof. Abbe. The experimental meltings were enlarged in scale the following year, and an experimental laboratory established for the continuation of the work at Jena. A chemist was added to the staff, and thus there were cooperating in this industrial research a glassmaker, a chemist, and a physicist. Before the end of 1883 the results had been so far successful that the Jena laboratory was in a position to make known to the world the processes for the "rational manufacture of optical glass." At this stage the experimenters were persuaded to put the results of their labour into practice, and the instrument makers, Messrs. Zeiss, having joined in, the Jena glass factory for producing optical glass on the commercial scale was established towards the end of 1884. In the first catalogue published by the Jena Works in 1886, we are told that forty-four optical glasses, nineteen being new in composition, were included. By 1888 the undertaking had been so successful that a supplementary catalogue was issued containing twenty-four additional glasses, of which thirteen were new, and in 1892 a second supplement announced the manufacture of eight more kinds of glass, of which six were new. Consider what this piece of work, prompted by science, fostered by the State, and carried out by a university professor in conjunction with a technologist has done for German industry. In the early stages of the experiments, before commercial results had been obtained, the experimenters were subsidised by the Prussian Education Department and by the Prussian Diet with a wise forethought which subsequent events have amply justified. Need I remind those who have come here to hear about bacteriology from Prof. Sims Woodhead how that science has advanced *pari passu* with the perfecting of the microscopic objective? The Zeiss instruments are now world-renowned, for it is obvious that a command over the processes for making glass with any particular optical properties that might be desired would enable the instrument maker to produce lenses suitable for other purposes, such as telescopes, field-glasses, photographic cameras, &c. I am afraid to dwell too much upon the perfection of the lenses of the Jena instruments because I lay myself open to the charge of holding a brief for a particular firm. If you want to know more fully what this optical glass industry has done for Germany, I refer you to the report on instruments of precision published in connection with the German exhibit at the Paris International Exhibition of 1900. As a further outcome the study of the properties of glasses of known composition in connection with their thermal and electrical behaviour has led to the manufacture of glass especially suitable for making thermometers, as also for electrical insulation, for the construction of the vacuum tubes used for producing Röntgen rays, and for the vessels employed in chemical laboratories. In brief, the manufacture of the finer kinds of glass has been placed upon a strictly scientific footing as the outcome of scientific research.

The next illustration which I propose to make use of refers to the applications of chemistry to agriculture. The growing plant, as you are aware, requires food for its growth just as much as the growing animal. Take an extreme case, and consider the size and weight of an oak tree as compared with the acorn from which it arose. This enormous accumulation of matter represents the assimilation of gaseous food in the form of carbon dioxide from the air through the leaves, and of water and nitrogenous and other mineral matter through the roots. It was the great German chemist Liebig who first established this broad principle of plant growth by systematic experiments upon various crops, and his results were given to the world in a work published in 1840, the English edition, edited by Lyon Playfair (afterwards Lord Playfair), bearing the title "Organic Chemistry in its Applications to Agriculture and Physiology." Perhaps few students consult this work now, but it was, strictly speaking, epoch-making on its appearance, because it brought the chemist into direct relationship with the farmer, and the consequence has been an enormous increase in the food-raising capacity of the soil. It is not necessary to inquire closely here into the motives that prompted Liebig's investigations—whether his work comes under the category of scientific researches directed towards a practical end, or whether he began with a desire of ascertaining abstract truth in the first place, and then found that his results were capable of practical application. It is quite immaterial from the present point of view how this work originated, because we are considering only the bearing of the results upon industry. It is evident that if a growing plant requires certain elements, such as potassium, sodium, phosphorus, nitrogen, calcium, magnesium, sulphur, chlorine, iron, &c., and if the soil by previous crops has been exhausted of some of these elements, it will not be possible to raise subsequent crops on this impoverished soil unless the necessary elements are supplied. In other words, the requisite elements must be added, and added in the form of compounds which the plant can make use of. Thus the great industry of crop-raising, and as connected therewith the feeding of farm stock, was shown to depend ultimately upon the chemical composition of the soil, and the manufacture of artificial manures or fertilisers has been the practical outcome of Liebig's researches.

Let us consider, further, the industrial results so far as these have influenced chemical manufactures. Prof. Warington can tell you all about the agricultural results. The elements which are most likely to fail, and which, in fact, have generally to be supplied, are potassium, phosphorus and nitrogen, excepting, of course, in the case of those particular leguminous plants which have developed a special means of fixing atmospheric nitrogen. Chemistry having thus been called upon to supply the agriculturist with compounds containing potassium, phosphorus and nitrogen, the first development which may be ascribed to Liebig's influence is the Stassfurt salt industry in Prussia, where immense deposits of salts containing potassium were known to exist. Similar deposits are found in Anhalt. The mining of these salts was commenced in 1860, and has proved an immense source of wealth to Germany, the total value of the Stassfurt and Anhalt salts produced down to 1890 being estimated at 11,500,000*l*., and since that time the output has gone on increasing from year to year. It is not necessary to weary you with statistics, but it is important to note how the demand for potassium salts for agricultural purposes has given rise to a great industry, for the natural salts, consisting chiefly of carnallite, a double chloride of potassium and magnesium and kainite, a double sulphate of potassium and magnesium with magnesium chloride, have to be submitted to various processes in order to separate the constituents, and the Stassfurt salt factories are now supplying Germany, as well as exporting large quantities of potassium chloride and sulphate, magnesium chloride and sulphate, potassium carbonate, caustic potash, &c.

In a similar way the demand for phosphates has given rise to the utilisation of every available source of these compounds. Calcium phosphate is found as the mineral apatite, a double calcium phosphate and chloride or fluoride occurring in vast deposits in America, and also in a less definite form in Canada, the West Indies, France, Belgium

and Germany. In this country calcium phosphate occurs in the form of coprolites, supposed to be the excreta of extinct saurians, in Cambridgeshire and elsewhere. All these natural phosphatic mineral deposits are mined, and have become valuable assets to the countries possessing them. The conversion of the minerals into a form suitable for the nutrition of crops is a branch of chemical industry involving the use of sulphuric acid for the conversion of the natural phosphate into the more easily assimilable form known as superphosphate. The greater part of the world's output of natural phosphates finds its way to Germany to undergo this treatment, the annual consumption of artificial manure in that country being estimated at something more than two million tons at a cost of about 5,000,000*l*. The mineral portion of the bones of animals, as you are no doubt aware, also consists largely of calcium phosphate, and before the mining of the mineral phosphates the conversion of bone ash into superphosphate was carried on on a very large scale. Bone ash is supplied now in large quantities from South America, but not much is converted into superphosphate, as the bones, after removal of the fat and the size (for glue), are capable of being finely ground, and are available for manure in this form.

Here is surely a romance of chemistry! The phosphates contained in the vegetation of the South American pampas go to build up the bony framework of the cattle which graze thereon. The skeletons of these beasts ultimately supply, let us say, the growing crop of a beet sugar manufacturer in Germany with phosphates. The phosphates picked out of the soil by South American vegetation concentrate in the bones of cattle, and are then sent into circulation in German beet. Or, even more striking, the phosphates accumulated by the great lizards of a remote geological age are now circulating through growing crops. This circulation of matter through the intervention of the living organism is an every-day story to the chemist. To our greatest poet apparently it was also known:—

> "Imperious Cæsar, dead and turn'd to clay,
> Might stop a hole to keep the wind away:
> O, that that earth which kept the world in awe,
> Should patch a wall to expel the winter's flaw!"

But we must descend from romance to reality. The deposits of sea birds also contain phosphates derived from the fish upon which they feed, and these deposits often accumulate in such large quantities as to make them available for agricultural purposes. Under the name of guano, immense quantities of this material, which contains both phosphates and nitrogenous matter, are exported from Peru. There is subject-matter for philosophising here, also, about the circulation of phosphates from marine organisms through birds into growing crops, and so forth, but time will not admit of many side disquisitions if I am to keep to my text. As another source of phosphate, it is of interest to know that the basic slag obtained in the Thomas-Gilchrist process of making steel is now largely used, so that the work set going by Liebig has, among its latest developments, led to the utilisation of a waste product of the steel industry.

Excepting in the case of leguminous plants, which are capable of utilising atmospheric nitrogen by a process which it does not come within my province to explain, the ordinary source of nitrogen for growing plants is a soluble nitrate, and if the soil is poor in such salts, they must be supplied either directly or indirectly through salts of ammonia, which are converted into nitrates in the soil by bacterial action in a way that nobody is better able to explain to you than Prof. Warington. The great natural deposits of sodium nitrate which occur in Chile and Peru supply practically all the nitrogen applied to the soil in this form for fertilising purposes. With respect to ammonia the destructive distillation of coal for the manufacture of gas and tar products, or for the production of coke, furnishes practically all the salts of this base required for agricultural and other purposes. The vital importance of assimilable nitrogen to growing crops has led the chemist also to study methods for the fixation of atmospheric nitrogen so as to render this element available for such purposes. It has long been known that nitrogen and oxygen can be made to combine under the influence of the electric spark. This, as you may remember, is one of the methods used by Cavendish in his classical researches on the composition of the air, and it was used also by Lord Rayleigh to separate atmospheric nitrogen from argon. Sir William Crookes has shown that the combustion can be brought about by the electric flame with such facility as to render the production of nitrite and nitrate by this process an industrial possibility, and the manufacture has actually been started in America by utilising the Falls of Niagara for the generation of the necessary electric power. Still more recently it has been found by Caro and Frank that when lime and coal are heated in the electric furnace, the calcium carbide fixes atmospheric nitrogen to form a compound known as calcium cyanamide, and this decomposes in the soil with the liberation of ammonia, so that the nitrogen of the air is thus rendered available for plant nutrition by an electrochemical process. The manufacture of this "Kalkstickstoff" is in the hands of the electrical engineering firm of Siemens and Halske, in Berlin.

There has been no straining of facts on my part in this sketch—necessarily brief—of the industrial results of Liebig's work. The establishment of the fundamental truths was a piece of pure scientific research. Had it not been made known by the irrefragable proofs furnished by scientific method that such and such elements were essential for plant growth, the mineral resources of the earth would have remained unused for this purpose. The minute percentage of nitrogen locked up in the fossilised vegetation of the Carboniferous period would never have been isolated in the form of ammonia and applied to the soil for the nourishment of the crops raised by the present day agriculturist. The successful cultivation of the beet as a source of sugar has been made possible by this knowledge, and it may be of interest to add that the further scientific study of the cultivation of that root in Germany has led to the yield of sugar being increased from $5\frac{3}{4}$ to 13 per cent. during the period commencing about the year 1840 and ending at the present time. The economic result of this industry upon our own sugar-growing colonies is a fiscal question which does not come within the province of this address.

Equally instructive as illustrating the connection between scientific research and industry is the production of alcohol and other valuable products through the agency of living organisms. The spontaneous conversion of saccharine solutions, such as the juice of the grape, into solutions containing alcohol, with the concurrent development of gaseous carbon dioxide, is among the earliest recorded observations in applied organic chemistry. The various theories which were from time to time advanced to explain what is called "fermentation" are now of historical interest only. It is to the researches of Pasteur that we are indebted for the placing of the fermentation industries on a scientific foundation. This illustrious chemist, who as far back as 1860–62 had successfully disproved the so-called "spontaneous generation" by showing that the ordinary air was always charged with living germs, turned his attention to the diseases of wine, with the object of assisting an industry of great national importance in France. His "Études sur le Vin" was published in 1872. A greater work—the great classic of the science of fermentation—appeared in 1876 under the title "Études sur la Bière." In this work it was definitely proved that the transformation of sugar into alcohol is a biochemical change; that the yeast which produces this change, and of which the organised nature had long previously been suspected, is, in fact, a low form of vegetable life allied to the fungi, and that it multiplies and grows at the expense of the sugar and other materials contained in the fermenting liquid, the alcohol and carbon dioxide being the products of its activity. It is now known, through the work of Buchner, that this chemical transformation of sugar into carbon dioxide and alcohol is the result of interaction between the sugar and a certain definite substance—an unorganised ferment—which is formed by the living yeast cell, and which can do its work independently of the cell in which it originated.

The scientific development of the fermentation industries followed from this and other work of Pasteur's. The names of those who have taken part in these later developments are numerous and illustrious, but want of time prohibits a detailed survey of this most fascinating chapter

of biochemistry. The leading idea that the formation of alcohol is a biochemical process depending upon certain organisms, or, as we may now say, upon the products of certain organisms, carries with it, as a necessary consequence, the conclusion that the industrial production of alcohol—whether for brewing or spirit distilling, or for the chemical manufacturer—is not an empirical or rule-of-thumb operation depending upon unknown conditions, but a definite chemical change produced in a definite way by a definite organism (yeast), and just as much under control as any other chemical operation. The chemist and the brewer have thus also been brought into association. The recognition that definite chemical transformations can be effected by microscopic forms of life which resulted from Pasteur's studies in wine and beer has had such far-reaching consequences that it is impossible to overestimate the importance of this work for the well-being of humanity. I should be encroaching upon the domain of Prof. Sims Woodhead were I to do more than remind you of the growth of that modern science—the most humanitarian of all the sciences—bacteriology, out of this fundamental conception. Keeping to the main topic of industrial results, one outcome has been, as I have said, to bring the operations of the brewer under scientific control. The organism, the yeast introduced into the vat to induce fermentation, must undergo careful microscopic examination to see that it contains no deleterious organisms, *i.e.* no organisms which would give rise to products other than alcohol. The water used by the brewer must be analysed to ascertain whether it contains the necessary mineral constituents for the nourishment of the yeast, because this plant is subject to the same conditions of growth as any other plant. Instead of obtaining its carbon from carbon dioxide, however, it can utilise sugar for this purpose, and it decomposes the sugar into carbon dioxide and alcohol in the way indicated.

The recognition of yeast as a vital chemical reagent which is apt to contain impurities in the form of wild or stray organisms which may damage the contents of the brewing vat, has led further to the introduction of the process of brewing by what is known as "pure culture yeast." This industry, of which the home is chiefly on the Continent, depends on the use of a yeast cultivated in the first place from a single cell of some particular species or variety or race by methods similar in principle to those adopted by the bacteriologist, the cultivation being carried on from generation to generation in carefully prepared solutions containing the necessary nutrient materials, sugar, nitrogenous matter, mineral salts, &c., and previously sterilised by heat so as to destroy every other form of life. The brewer can now be supplied, as the outcome of a series of brilliant investigations by Hansen, of Copenhagen, to whom he is indebted for this purification of the biological foundation of his industry, with a cultivated yeast as pure in strain as a pedigree horse or a particular breed of dog —a yeast which, by virtue of its purity, can be depended on for giving constant results in the brewing vat. This is another illustration of the relationship between research and industry.

Consider, in the next place, the sugar which the yeast decomposes by virtue of its zymase. In an ordinary brewing operation the liquor which is fermented is not supplied in the first place with sugar as such, but the starch contained in the barley grain is ultimately broken down, as chemists say, into sugar by virtue of certain processes which I cannot stop to explain. But the broad fact is that yeast cannot feed upon starch, but only upon sugar, and, in fact, only upon certain kinds of sugars, and the starch which is stored up in the barley is the raw material which ultimately supplies the necessary kind of sugar. So that starch, which, as you know, is a substance very widely distributed in the vegetable kingdom, can be extracted if necessary from the seeds or tubers which contain it, and converted into sugar by chemical processes, and then used for the production of alcohol. An important industry is flourishing in Germany at the present time for the production of alcohol from potato-starch. In Berlin a few weeks ago we were shown over a large establishment entirely devoted to the fermentation industries, and potato spirit and other products from the potato were the most conspicuous features of the exhibition. Now alcohol is a substance of great importance for chemical industry in many directions, and its inflammability makes it valuable as a fuel, so that the problem of the cheap production of alcohol is worthy of the serious attention of investigators. It is interesting to contemplate the period when our natural sources of fuel, coal and petroleum, are all exhausted, and when we may have to fall back upon the vital activity of a lowly form of vegetable life to supply us with liquid fuel. Scientific research has helped here, also, to call a new industry into existence, because the cost of alcohol, like that of any other chemical product, is obviously dependent upon the yield, *i.e.* upon the quantity obtainable from a given weight of raw material. I must claim your indulgence while I trace in brief outline one of the most beautiful of the modern industrial developments of the principles of fermentation.

It had long been known that in Java an alcoholic beverage, known as arrack, was prepared by fermenting molasses with a peculiar ferment prepared by a special process from rice. From what has been previously said, you will understand that the starch contained in rice is not, as such, available for direct alcoholic fermentation. A detailed scientific investigation of the starch-fermenting materials used in Java and elsewhere in the Far East has revealed the fact that these ferments owe their activity to the joint action of two out of several different organisms which are contained in them. One of these is a mould fungus which has the property of saccharifying starch, *i.e.* breaking it down into sugar, and thus rendering it available for the growth of the other organism, which is a yeast capable of exciting alcoholic fermentation in the usual way. Now the principle revealed by the scientific study of these eastern ferments has been developed into an industrial process for producing alcohol from starch of any origin, such as from maize, rice, potato, &c. The operations, in the briefest possible terms, consist in saccharifying the prepared starch by a pure culture of mould fungus, and then fermenting by means of yeast. The problem of increasing the yield of alcohol has thus been solved; not only is the spirit obtained in more concentrated form, but the actual percentage of alcohol furnished by a given weight of starch is much greater than has ever been obtained by any of the older processes of fermentation.

I have left but little time for dealing with an industry with which I have had long personal connection—the manufacture of colouring matters and other products from coal tar. The relations between scientific research and this industry are so intimate, and are so frequently referred to in public, that it has become a kind of stock example for the use of those who wish to emphasise the interdependence of science and industry. The history of this industry, moreover, is particularly instructive from our present point of view, because it originated in this country in 1858 and flourished here for a period of about twenty years, and then began to decline. The chief centre of activity for the production of coal tar products at the present time is Germany, where there are six large factories and a number of smaller ones. The aggregate capital of the six large factories amounts to some 3,000,000*l.*, and they give employment to about 20,000 people, including chemists, engineers, clerks and travellers, dyers and draughtsmen, workmen, &c. These large firms pay dividends varying between 5 and 25 per cent. upon their capital. The total value of the tar products manufactured in Germany exceeds 10,000,000*l.* annually, and she supplies by far the largest proportion of the dye-stuffs used throughout the world. When, in 1886, I proclaimed our approaching fate with respect to this industry, I found that we were then using about 90 per cent. of German and other foreign colouring matters in this country, and my friend, Prof. Arthur Green, of the Yorkshire College, finds that things are in about the same state at the present time.

The coal tar colour industry arose, in the first place, from an observation made by Dr. W. H. Perkin in 1856 in the course of a research having for its object the synthesis of quinine. He did not succeed in producing the alkaloid but he noticed that aniline, when oxidised, gave a colouring matter, which he manufactured and introduced under the name of "mauve," and so laid the foundations of an industry which has developed to its present colossal dimensions. The art of the dyer and calico-printer has been

absolutely revolutionised by the introduction of the synthetical colouring matters prepared from coal tar. Of these more than 500 are now available—each one a distinct and definite chemical compound with characteristic colour; each one with properties rendering it suitable for application to particular classes of fabrics. Every range of colour, including the deepest black, can be imparted, and every degree of brilliancy or dullness, of fastness to light, to washing and bleaching agents, &c., can be realised as required. The natural dye-stuffs, such as madder, which supplied alizarin for Turkey red; the cochineal insect, which furnished a red dye; the lichens and dyewoods, which were used by the old-time dyers, have been displaced, or are on the way to displacement, by the tar products. The most important of all the natural colouring matters, indigo, is, as you know, among the latest of the achievements of industrial synthetical chemistry, and a great industry worth some 3,000,000*l*. annually to our Indian Empire is threatened with extermination by the German manufacturers. Not a month passes without the introduction of new colouring matters, and so enterprising are the German colour makers that their pattern-books are issued with full directions in various languages, and trained chemists in their service will give personal instructions to our dyers in the application of new and unfamiliar colouring matters.

It is impossible to do more than allude in passing to the enormous influence of this greatest and most refined of all the chemical industries upon every other department of chemical manufacture. It has reacted, and is reacting, with ever multiplying ramifications upon the manufacture of the raw materials such as acids and alkalis, it is revolutionising the methods for producing sulphuric acid, it is pressing into its service electrolytic processes, and it has created new branches of engineering for the construction of special plant and machinery. The utilisation of the infinity of compounds present in the tar is no longer restricted to the production of colouring matters. Valuable medicinal preparations, photographic materials, perfumes, antiseptics, the sweet-tasting saccharin, which is 300 times sweeter than sugar, an artificial musk which exceeds in intensity of odour any natural musk, are among the manufactured products from coal tar. The industry is the direct outcome of scientific research; it has been developed by research, and is being still developed by research. Both methods referred to in this address have been, and are, at work. The by-results of pure scientific investigation are seized upon whenever they show the slightest chance of being industrially useful. Saccharin is such a by-result. The chemical reactions which culminated in the industrial production of indigo were published by their discoverer, the late Dr. Heumann, as an academic discovery in the first place, and were developed industrially by the "Badische Anilin und Soda Fabrik" of Ludwigshafen. By the other method whole armies of highly trained scientific chemists are constantly at work in the splendidly equipped research laboratories of the German factories investigating new products and processes with the direct object of their ultimate industrial application. Nor must it be forgotten that under the term "research" used in this connection is comprised also theoretical research. A close study of the history of this industry will show how throughout it has been vitalised by theoretical conceptions concerning the chemical structure of the molecules of organic compounds, and especially by the so-called benzene ring theory of Kekulé, now so familiar to chemical students. The force of illustration of the connection between science and industry can, perhaps, go no further than in this case, where a purely abstract conception based on a knowledge of the properties of the atom of carbon has reacted upon a branch of manufacture to its lasting benefit.

I have thought it best to limit my treatment to the record of bare facts in order to bring home to you in a concrete way how chemical industry and chemical research are interdependent. Four groups of industries have been dealt with; it would have been easy to subdivide the subject and to deal with four dozen. I must confess that I am getting rather tired of what may be called the platform treatment of education in applied science, which consists in general of the purely clerical or office-boy work of compiling information—doubtless very valuable in its way—concerning the number of schools in foreign countries, the acreage of land which they cover, their cubic contents, cost of erection and maintenance, the number of professors and staff, and the number of students which they turn out annually. The reason why this kind of information is getting stale and wearisome is because it produced at first no effect at all in this country, and then it led to a reckless expenditure in bricks and mortar, and the starting of institutions which are inadequately endowed, insufficiently maintained, and altogether lower in their working capabilities than the continental institutions which prompted their foundation. I thought, therefore, that it might be more acceptable if, instead of dealing with the usual generalities of the statistical order, I sketched the history of a few specific industries. If it appears that Germany has played a very prominent part in these histories, all I can say is that there has been no intentional selection on my part, but it is entirely due to the circumstance that it is to that country more than to any other that industry owes its advancement by scientific method. The preeminence of Germany in chemical industry is sufficiently notorious, as our own manufacturers know to their cost. The most striking feature of the exhibition at Paris in 1900, when, as a member of the International Jury for Chemical Products, I had occasion to examine the exhibits of all countries, was the collective exhibit of chemical products displayed by some ninety German firms. This splendid collection, which revealed more than anything the enormous advances made in chemical industry by Germany, is now deposited in a special building in the grounds of the Technical High School at Charlottenburg.

So much has been said and written about the causes of this wonderful development of German chemical manufactures that I hesitate to add anything more to the discussion. Certainly it is not possible to add anything new. Those who, like Prof. Michael Sadler and Dr. Rose, have made a special study of German educational systems have placed before the public valuable reports in which these causes are fully discussed from the educational point of view.[1] In the official report to the French Government on the products of Class 87, Prof. Haller, the secretary to our jury and author of the report, has devoted a whole section to the "Causes de la Prospérité de l'Industrie chimique Allemande." The general conclusion to which we have all come concerning this remarkable industrial development is that it is mainly due to the higher educational level in Germany with respect more especially to the highest scientific instruction in the universities and technical high schools. It is perhaps permissible to go one stage further back, and to say that this advanced scientific education is in itself the expression of the public faith in such education, and the recognition by the State of the industrial value of such training. It has been well pointed out that the money invested by the German nation in founding and maintaining the chemical chairs at the universities and technical high schools is now worth some 50,000,000*l*. annually to the country in this branch of industry alone. More especially, also, it may be claimed that the recognition of the value—the indispensable value—of scientific research to industry by the manufacturers themselves has been one of the most potent factors in developing German chemical industry, and the lack of such appreciation on the part of our own manufacturers has been one of the chief causes of their decadence.

In so far as the subject under consideration is an educational one, it comes within the province of a gathering of students held under the auspices of the most ancient seats of learning in this country. At any rate, the topic is one of such supreme importance to the welfare of this nation that I could not resist the invitation to take part in your proceedings, because the question is one which has been for years undergoing the most serious consideration by those who have, like myself, been connected on the one

1 See especially vol. ix. of the special reports issued by the Board of Education, entitled "Education in Germany," by Prof. Sadler. Also Dr. Rose's diplomatic and Consular reports, issued by the Foreign Office, No. 561, "Chemical Instruction and Chemical Industries in Germany"; No. 591, "German Technical High Schools"; No. 594, "Agricultural Instruction in Germany and the Development of German Agriculture and Agricultural Industries."

hand with manufacturing industry and on the other hand with the teaching of science. Whether the old universities are desirous of making a new departure and of enlarging their spheres of activity so as to bring them more into harmony with the practical requirements of the age I have no authority to discuss. Certainly Cambridge, by the establishment of departments of engineering and agriculture, has made a distinct advance in this direction. At any rate, it may be taken as a sign of the times that the relationship between science and industry has been made a special feature of this year's university extension meeting, and the outer world will no doubt take due cognisance of the circumstance that a subject has been chosen for consideration which, in this country, is generally considered quite remote from the higher ideals of university education.

It is evident from what has long been going on in Germany and America, and from what is now taking place with regard to education by our newer universities here, that applied science is, or can be, brought within the province of university education. Of course, if the view be held that science is degraded by being turned to practical account, then we must not look to the universities for the training of our industrial leaders. It is impossible, however, to note the progress of events since the coalescence of science and industry abroad without coming to the conclusion that the position of a nation in the scale of civilisation will be measured in the future by its productive energy —by the capacity of its workers to evolve new ideas and to carry them out practically; by the number, zeal and originality of its scientific workers, and by their mastery over the resources of nature. I do not mean to imply that the old universities have done nothing towards the education of scientific thinkers and workers. What strikes outsiders like myself is the very small part that these universities are taking in the modern equipment of the great industrial army of Britain as compared with the work being done by foreign universities for their respective countries. In view of the industrial struggle between nations which has arisen through the discoveries of modern science—a struggle which is bound to become keener with the progress of science—it cannot be seriously maintained that the material welfare of our country is beneath the dignity of even the most profound academic scholar. The old definition of a university as an educational centre for the cultivation of useless knowledge no longer holds good. If there are universities which still cling to this tradition concerning their functions, it may safely be predicted that their influence in moulding the future life of the nation is destined to shrink to smaller and smaller dimensions.

The part played by the German universities and technical high schools in the training of technologists is now so well known in this country that a detailed restatement of the facts is hardly necessary. I may remind you that their twenty universities, with foundations dating from the fourteenth to the beginning of the nineteenth century, for many years supplied the factories with men thoroughly trained in science, and capable of applying their knowledge to industrial processes. With the development of manufacturing industry along scientific lines it was found necessary to provide more specialised education, and during the first half of the nineteenth century trade schools or polytechnics were called into existence in nine different centres. Of course, you know that our polytechnics here have very little analogy with the German institutions of that name. The polytechnics were in time found inadequate to meet the growing requirements of German industrial training, and their functions were accordingly enlarged and their educational status raised. Out of these nine polytechnics or trade schools have arisen nine technical high schools, and two more such schools are now in course of erection. Thus in Germany both universities and technical high schools are catering for the scientific needs of the national industries. I may add that a few years ago there was a serious discussion in Germany among certain educational bodies and industrial organisations as to whether the State should not be asked further to strengthen the scientific faculties of the universities by creating chairs of technical or applied chemistry, and although there has been no practical outcome of this movement as yet, it is an instructive illustration of the spirit which is abroad in that country.

There is very much misapprehension here concerning the nature and functions of the German technical high schools. They are not glorified polytechnics of our own type for teaching handicrafts to artisans or smatterings of science to ill-prepared students. They are institutions of university rank—their education is of university standard, and their professors stand on a level with the professors of the universities. Their students are not admitted until they have reached a high standard of general secondary education. Their courses of instruction are as purely scientific as the university courses, and the only difference between the two kinds of education is that the technical high school is all scientific, and the various sciences are taught both theoretically and practically with a view to their ultimate industrial applications. It is a " technical education " in the highest and best sense, and not in the narrow—I may even say degraded—sense in which the term is so frequently used in this country.

The question of the hour which the old universities have now to face is whether they are willing to take part in the newer education required by our industrial leaders, whether they are prepared to strengthen and develop the teaching of those physical sciences which underlie productive industry, and to recognise the claims of the applied sciences as subjects worthy of inclusion in their curricula. There will, of course, be a divergence of opinion with regard to this question. There will be the old, old conflict between the advocates of the " humanising " influence of the ancient classical studies and the supporters of modern scientific education. So far as my opinions are worth anything, I cannot see, and I never could see, why a study of nature at first hand should be less " humanising " than the study of those classical subjects which have so long held the field. I admit that the teaching of the physical sciences as they should be taught at the present time in any institution of university rank is more costly—that the equipment consists of something more than a library, and that their teachers, to be effective, should be themselves active investigators, inspiring originality and a desire for creating new knowledge in their students. I can understand that a subject which to the classical don wears the aspect of a financial ogre should be kept down as long as he has a preponderating influence in regulating the affairs of his university. But this is a matter of expediency, and not a real conflict between fundamental principles. I cannot find that the classical teaching of the American or German universities has been impaired by the splendid development of their scientific faculties; neither does it appear that the human products of their scientific activities are in the least degree inferior as men to their classical scholars. Of course, I am a special pleader, and I am making the best use of my opportunities, and I repeat that I never could see where any antagonism existed between the older and the newer studies excepting in the struggle for financial means. There are many educational authorities here and abroad who will tell you that the scientific development of the German universities has reacted upon and improved the classical teaching by an infusion of scientific method into the latter. Moreover, it must be remembered that we who are advocates for the new education are not clamouring, as many people think, for the abolition of the old studies. I for one should deplore any falling off in the prestige of the old universities as seats of classical learning. Neither is it suggested that our future leaders of industry would never at any period of their studies derive benefit from that particular kind of culture which the ancient literature is capable of imparting. I firmly believe they would; but the question as to when and how would open up the whole field of education, elementary, secondary, and university, both pre- and post-graduate, and I should find myself floundering among shoals and quicksands in no time. The ideal university is one that offers facilities for both the older and the newer education; they are not mutually exclusive—they can, and do, thrive side by side elsewhere, and there is no reason, at any rate no theoretical reason, why they should not do so here.

The form in which the question may be put is therefore whether, given the means, the older universities should

develop their work in the direction of applied science. A large body—I cannot say how many—of outsiders who are well-wishers of these universities is of opinion that they should, and there is an idea abroad that they are suffering financially now from having neglected this side of education in the past. There was, for example, a leading article in the *Times* of May 25 in the course of which the writer suggests that they may have suffered through having a false reputation for being very wealthy bodies, and he adds:—"Or is it perchance, because the modern millionaire, being a man of his age and an Englishman to boot, has no great belief in the economic value of knowledge as such, and no great confidence in the capacity of our ancient universities to adapt themselves to the needs of the coming time?" Now, so far as the chemical manufacturers of this country are concerned, I can say with some personal experiences of my own that they certainly have shown no great belief hitherto in the economic value of scientific knowledge, as they now know to their own cost. But if, to make a purely hypothetical conjecture, some beneficent millionaire were to test the capacity of our old universities for undertaking this kind of work, and were to offer adequate means for the purpose, I feel pretty confident, from what I know of the spirit which dominates their governing bodies, that such an offer would be accepted both at Cambridge and here at Oxford with few dissentients. If such a departure were placed within their power, I think that that great public which glories in the past achievements of these universities would rejoice in their new development. And I will further add that the creation of chairs of applied science would react upon and strengthen the teaching of all those sciences which are in any way connected with industrial productiveness.

Of course, this is all hypothesis—the most nebulous of hypotheses. We all know, unfortunately, that the financial resources of the universities have been, and are, inadequate for the purpose of enabling them to meet the requirements of modern scientific education, either in the way of staff, accommodation, or equipment. It can be said, and justly said, that so long as these universities are without the means of developing their schools of pure physical science to an extent worthy of their reputation, it is useless to talk about developing the teaching of applied science. So it may be. But I remind you that we are still in the region of hypothesis, and the captious critic might retort by saying that they have not done even as much as they might, and could, have done for the proper development of scientific teaching with the means already at their disposal—that they are still overweighted by ancient tradition, and that their internal scientific forces are still feeble as compared with the preponderating forces of the advocates of the older culture. There is no time, even if I knew enough about the inner mechanism of university administration, to discuss this aspect of the question, but if you want to know an American view of the case—a strong view!—I would invite attention to an address by Prof. Victor Alderson, Dean of the Armour Institute of Technology, delivered before the Chicago Literary Club in October last year, an abstract of which was published in NATURE of February 12.

The question of the recognition of applied science by our old universities must, as I said, be faced—the time is at hand for them to consider seriously whether it is desirable that they should cater for the training of those who are destined to be the founders and upholders of our national prosperity. The longer this question is shelved the smaller will grow the chances of their being able to participate in the work. At present we in this country are not up to the German level so far as concerns the higher technical training of industrial leaders. Our universities, in other words, have not yet had to encounter the full force of competition with newer institutions of the rank of the technical high schools. We have but very few, if any, schools of this status here now, but if I read the signs of the times correctly, the differentiation between the old and the new education—which has already become well marked—is bound with the progress of science to become more and more strongly pronounced. Our newer universities—especially those in large manufacturing centres—will be driven more and more into the teaching of applied science, and our polytechnics and technical colleges will perforce have to raise their educational standard. The effect cannot but be to cause the older universities to become of smaller importance in the general scheme of national education as time goes on. That is why I have taken advantage of the opportunity which has been placed in my hands for raising this note of alarm, because even if nothing practical results from this meeting, it may at any rate be useful to let it be known that many of us desire to see the most ancient and the most renowned of our educational foundations doing more for the education of a nation the prosperity of which is so largely dependent on productive industry.

Whether as the outcome of the lectures delivered and the conferences held during this meeting the attitude of the universities towards applied science undergoes modification or not, the ventilation of opinions cannot but be of advantage in many ways. If, for example, it is made manifest that the current of national thought is moving slowly—alas! very slowly—towards the recognition of science as the main factor of industrial progress, it may help to emphasise the necessity for strengthening and developing the teaching of pure science. If the beneficent millionaires are not forthcoming for the purpose of endowing applied science, there is, at any rate, ample scope for their beneficence in the endowment of pure science in our old universities. A school of active science workers would—to use a quasi-scientific expression found in the pages of many writers of fiction—"galvanise into life" the science teaching of the schools. If you can only help to mould the public mind into the belief that science is a living reality veiling truths of inestimable value to humanity from every point of view, moral, social and material—truths that are to be wrested only by conscientious, laborious and persistent *research*—you will be assisting a great cause. If you will proclaim this doctrine from the house-tops and assist in sweeping away that dust heap of formal text-book knowledge which passes for science in our examination rooms you will be doing something towards raising the general level of opinion in this country. We need it badly! Think of all the creative intellectual power running to waste—the unrealised assets in the way of originality of thought which Great Britain might have at her disposal if the brain power of her teachers and students were only diverted into the right channels. The old universities, by virtue of their prestige, their traditions, and their past achievements, have still a powerful hold upon the public mind. They must open their doors still more widely to science if they wish to retain their hold. If their means are at present insufficient to enable them to meet the requirements of the age, they can still forward the national cause by upholding the dignity of science, by insisting upon originality of thought as an essential qualification for its successful teaching, and by helping to dispel the notion that it undergoes degradation by being applied to human welfare. It must be realised, and it cannot be realised too soon, that the peaceful campaign of industrial competition requires leaders well trained in scientific method, and not crammed with mere formal book learning—men as alert in mind and resourceful in meeting difficulties, as upright in principle, as keen in enthusiasm, as far-seeing in imagination, and with as intimate a knowledge of human nature as the statesmen, warriors, divines, lawyers, and schoolmasters which these old universities have given to their country. The victory of the future is with that nation which enables her children to approximate more closely towards Tennyson's ideal:—

> ". . . the crowning race
> Of those that eye to eye shall look
> On knowledge; under whose command
> Is Earth and Earth's; and in their hand
> Is Nature like an open book."

IRRIGATION WORKS.

INDIA.

In a recent number of the *Revue générale des Sciences* is an article on irrigation in India which is interesting as showing the impression made on the mind of a foreigner after an inspection of the great works that have been carried out under the British administration for mitigating the